3. Dynamics

3.3 Linear momentum and its conservation

Paper 2

Question Paper

1 **(a)** State the principle of conservation of momentum.

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.....

..... [2]

(b) An object of mass $2m$ is travelling at a speed of $5.0\,m\,s^{-1}$ in a straight line. It collides with an object of mass $3m$ which is initially stationary, as shown in Fig. 3.1.

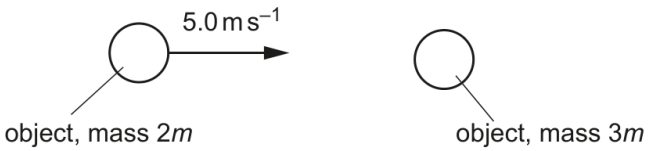


Fig. 3.1

After the collision, the object of mass $2m$ moves with velocity v at an angle of 30° to its original direction of motion.

The object of mass $3m$ moves with velocity w also at an angle of 30°, as shown in Fig. 3.2.

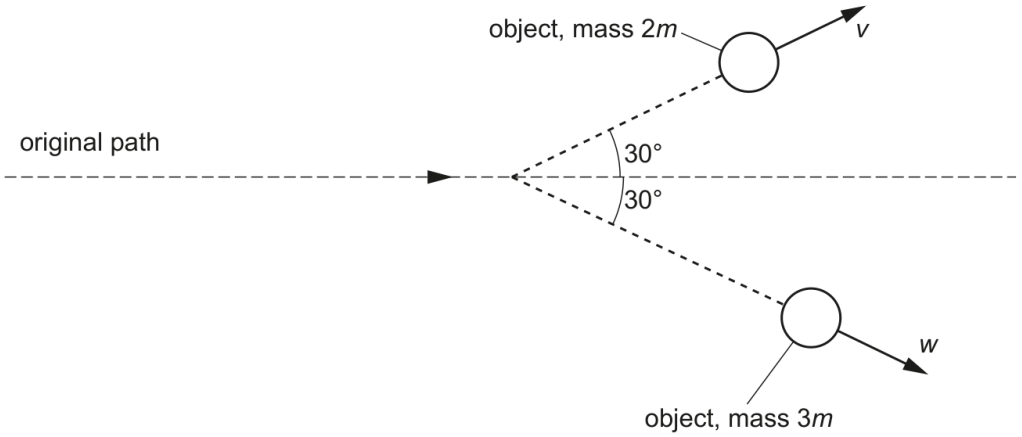


Fig. 3.2

By considering the conservation of momentum in two dimensions, calculate the magnitudes of v and w.

v = ... $m\,s^{-1}$

w = ... $m\,s^{-1}$

[4]

2 **(c)** Before the α-decay, P is travelling at a constant velocity. After the decay, Q has a velocity of $1.3 \times 10^5\,m\,s^{-1}$ at an angle of 68° to the original path of P.
The α-particle has a velocity of $150 \times 10^5\,m\,s^{-1}$ at an angle of θ to the original path of P, as shown in Fig. 6.2.

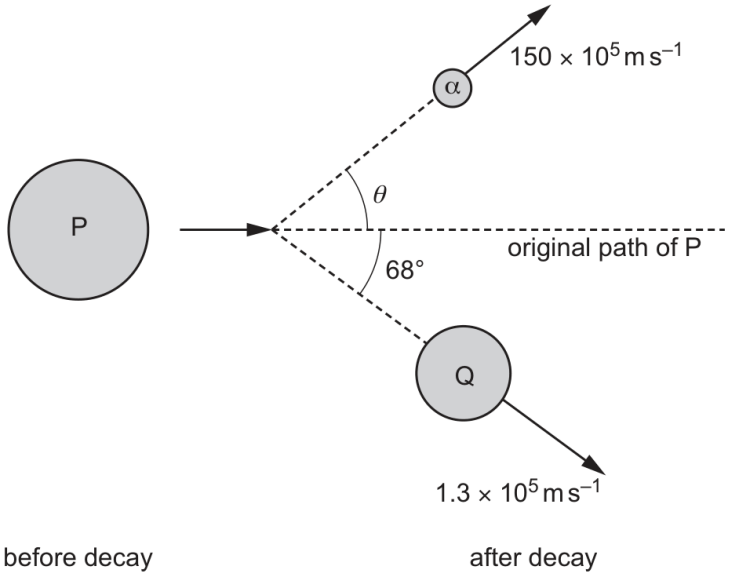


Fig. 6.2 (not to scale)

(i) Use the principle of conservation of momentum to determine θ.

θ = ...° [3]

3 An isolated stationary nucleus X decays by emitting an α-particle to form a nucleus Y.

Nucleus Y and nucleus Z are isotopes of the same element.

(b) Use the principle of conservation of momentum to explain why nucleus Y cannot be stationary immediately after the decay of nucleus X.

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..... [2]

4 A trolley A moves along a horizontal surface at a constant velocity towards another trolley B which is moving at a lower constant speed in the same direction. Fig. 3.1 shows the trolleys at time $t = 0$.



Fig. 3.1

Table 3.1 shows data for the trolleys.

Table 3.1

trolley	mass / kg	initial speed / m s^{-1}
A	0.25	0.48
B	0.75	0.12

The two trolleys collide elastically and then separate. Resistive forces are negligible.

Fig. 3.2 shows the variation with time t of the velocity v for trolley B.

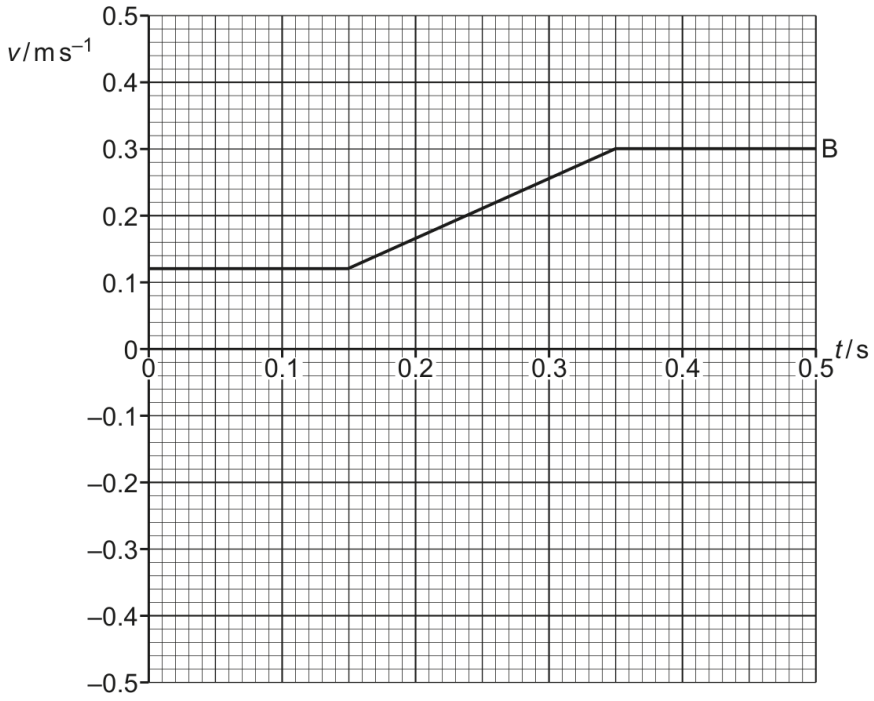


Fig. 3.2

(b) Use Table 3.1 and Fig. 3.2 to determine:

(ii) the magnitude and direction of the final velocity of trolley A.

magnitude = ... $m\,s^{-1}$

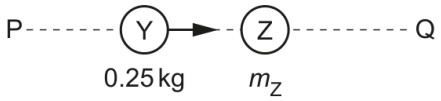
direction .....

[3]

(c) On Fig. 3.2, sketch the variation of the velocity of trolley A with time t from $t = 0$ to $t = 0.50\,s$.

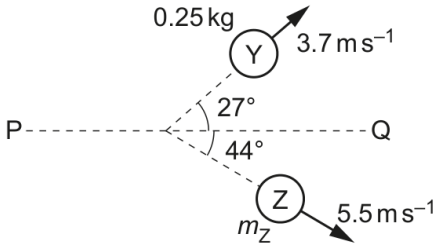
[3]

5 **(a)** A ball Y moves along a horizontal frictionless surface and collides with a ball Z, as illustrated in the views from above in Fig. 4.1 and Fig. 4.2.



BEFORE COLLISION

Fig. 4.1 (not to scale)



AFTER COLLISION

Fig. 4.2 (not to scale)

Ball Y has a mass of 0.25 kg and initially moves along a line PQ.
Ball Z has a mass m_Z and is initially stationary.

After the collision, ball Y has a final velocity of 3.7 m s^{-1} at an angle of 27° to line PQ and ball Z has a final velocity of 5.5 m s^{-1} at an angle of 44° to line PQ.

(i) Calculate the component of the final momentum of ball Y in the direction perpendicular to line PQ.

component of momentum = ... N s [2]

(ii) By considering the component of the final momentum of each ball in the direction perpendicular to line PQ, calculate m_Z.

m_Z = ... kg [1]

(b) Two blocks, A and B, move directly towards each other along a horizontal frictionless surface, as shown in the view from above in Fig. 4.3.



Fig. 4.3

The blocks collide perfectly elastically. Before the collision, block A has a speed of $4\,m\,s^{-1}$ and block B has a speed of $6\,m\,s^{-1}$. After the collision, block B moves back along its original path with a speed of $2\,m\,s^{-1}$.

Calculate the speed of block A after the collision.

speed = ... $m\,s^{-1}$ [1]

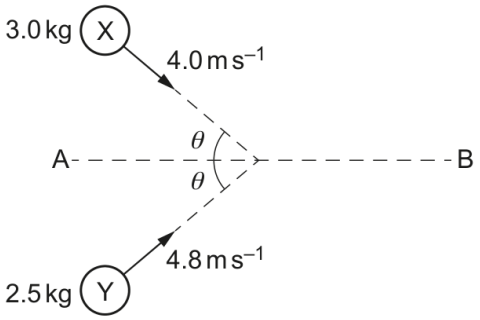
6 **(a)** State the principle of conservation of momentum.

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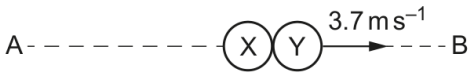
..... [2]

(b) Two balls, X and Y, move along a horizontal frictionless surface, as shown from above in Fig. 4.1.



before collision

Fig. 4.1 (not to scale)



after collision

Fig. 4.2 (not to scale)

Ball X has a mass of 3.0 kg and a velocity of 4.0 m s^{-1} in a direction at angle θ to a line AB. Ball Y has a mass of 2.5 kg and a velocity of 4.8 m s^{-1} in a direction at angle θ to the line AB.

The balls collide and stick together. After colliding, the balls have a velocity of 3.7 m s^{-1} along the line AB on the horizontal surface, as shown in Fig. 4.2.

(i) By considering the components of the momenta along the line AB, calculate θ.

θ = ... ° [3]

(ii) By calculation of kinetic energies, state and explain whether the collision of the balls is inelastic or perfectly elastic.

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..... [2]

7 A stationary nucleus P of mass 243 u decays by emitting an α-particle of mass 4 u to form a different nucleus Q, as illustrated in Fig. 7.1.

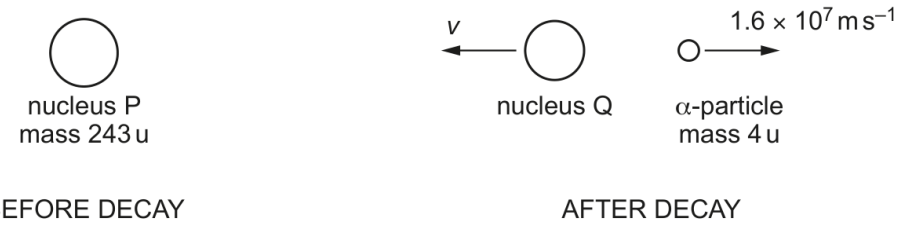


Fig. 7.1

The initial speed of the α-particle is $1.6 \times 10^7\,\text{m s}^{-1}$.

(a) Use the principle of conservation of momentum to explain why the initial velocities of nucleus Q and the α-particle must be in opposite directions.

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.....

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..... [2]

(b) Determine the initial speed v of nucleus Q.

v = ... m s^{-1} [2]

8 A block X slides along a horizontal frictionless surface towards a stationary block Y, as illustrated in Fig. 2.1.

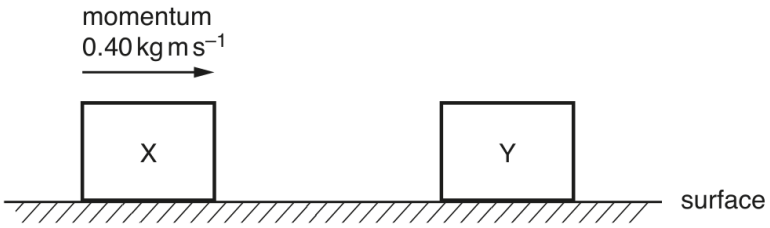


Fig. 2.1

There are no resistive forces acting on block X as it moves towards block Y. At time $t = 0$, block X has momentum $0.40\,\text{kg m s}^{-1}$. A short time later, the blocks collide and then separate.

The variation with time t of the momentum of block Y is shown in Fig. 2.2.

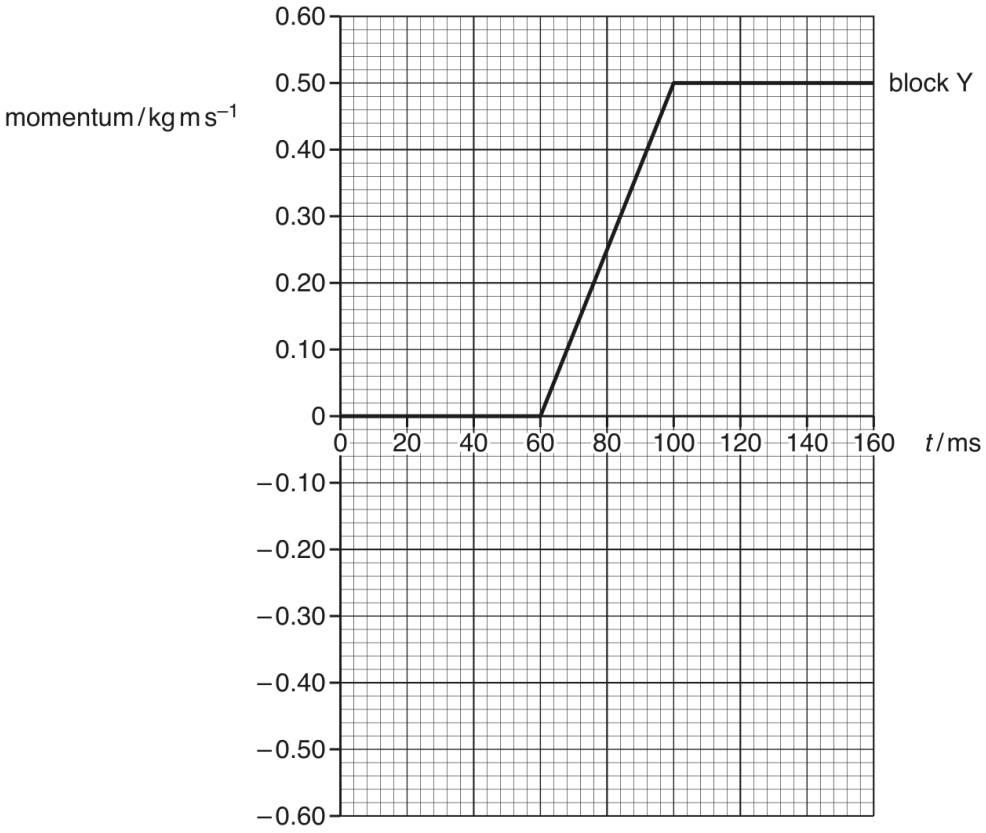


Fig. 2.2

(d) On Fig. 2.2, sketch the variation of the momentum of block X with time t from $t = 0$ to $t = 160\,\text{ms}$. [3]

9 **(b)** A block X of mass m_X slides in a straight line along a horizontal frictionless surface, as shown in Fig. 3.1.

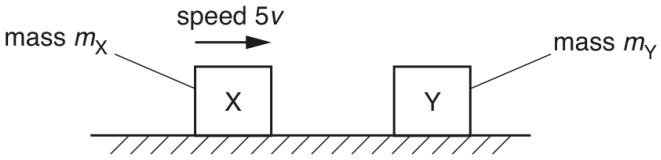


Fig. 3.1

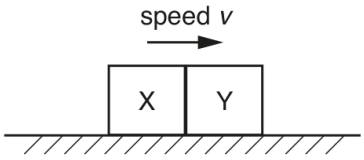


Fig. 3.2

The block X, moving with speed $5v$, collides head-on with a stationary block Y of mass m_Y. The two blocks stick together and then move with common speed v, as shown in Fig. 3.2.

(i) Use conservation of momentum to show that the ratio $\frac{m_Y}{m_x}$ is equal to 4.

[2]

(ii) Calculate the ratio

$$\frac{\text{total kinetic energy of X and Y after collision}}{\text{total kinetic energy of X and Y before collision}}.$$

ratio = ... [3]

(iii) State the value of the ratio in **(ii)** for a perfectly elastic collision.

ratio = ... [1]

(c) The variation with time t of the momentum of block X in **(b)** is shown in Fig. 3.3.

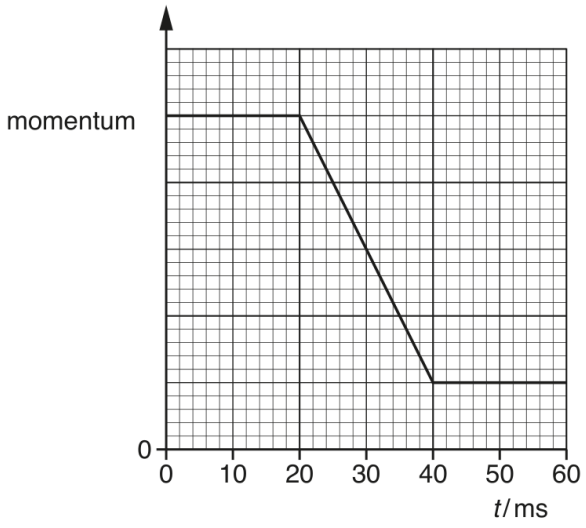


Fig. 3.3

Block X makes contact with block Y at time $t = 20$ ms.

(ii) On Fig. 3.3, sketch the variation of the momentum of block Y with time t from $t = 0$ to $t = 60$ ms. [3]

10 (b) Two blocks travel directly towards each other along a horizontal, frictionless surface. The blocks collide, as illustrated in Fig. 3.1.

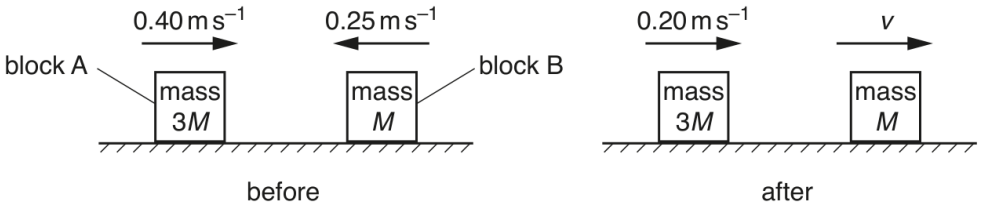


Fig. 3.1

Block A has mass $3M$ and block B has mass M.
Before the collision, block A moves to the right with speed $0.40\,m\,s^{-1}$ and block B moves to the left with speed $0.25\,m\,s^{-1}$.
After the collision, block A moves to the right with speed $0.20\,m\,s^{-1}$ and block B moves to the right with speed v.

(ii) Determine speed v.

v = ... $m\,s^{-1}$ [3]

(iii) Calculate, for the blocks,

1. the relative speed of approach,

relative speed of approach = ... $m\,s^{-1}$

2. the relative speed of separation.

relative speed of separation = ... $m\,s^{-1}$
[2]

(iv) Use your answers in **(b)(iii)** to state and explain whether the collision is elastic or inelastic.

.....

.....[1]

11 **(a)** State the principle of conservation of momentum.

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.....[2]

(b) A stationary firework explodes into three different fragments that move in a horizontal plane, as illustrated in Fig. 2.1.

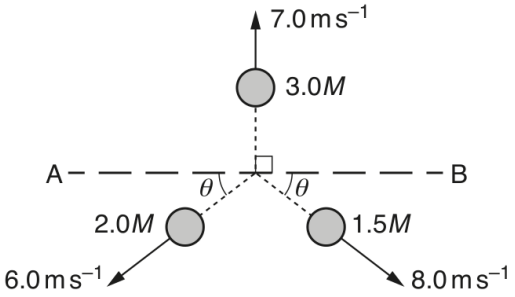


Fig. 2.1

The fragment of mass $3.0M$ has a velocity of $7.0\,m\,s^{-1}$ perpendicular to line AB.
The fragment of mass $2.0M$ has a velocity of $6.0\,m\,s^{-1}$ at angle θ to line AB.
The fragment of mass $1.5M$ has a velocity of $8.0\,m\,s^{-1}$ at angle θ to line AB.

(i) Use the principle of conservation of momentum to determine θ.

θ = ... ° [3]

12 A wooden block moves along a horizontal frictionless surface, as shown in Fig. 2.1.

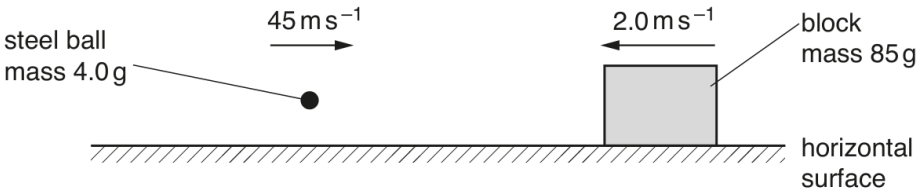


Fig. 2.1

The block has mass 85 g and moves to the left with a velocity of 2.0 m s^{-1}. A steel ball of mass 4.0 g is fired to the right. The steel ball, moving horizontally with a speed of 45 m s^{-1}, collides with the block and remains embedded in it. After the collision the block and steel ball both have speed *v*.

(a) Calculate *v*.

v = ... m s^{-1} [2]

(b) **(i)** For the block and ball, state

1. the relative speed of approach before collision,

relative speed of approach = ... m s^{-1}

2. the relative speed of separation after collision.

relative speed of separation = ... m s^{-1}
[1]

(ii) Use your answers in **(i)** to state and explain whether the collision is elastic or inelastic.

.....

..... [1]

13 (a) State the principle of conservation of momentum.

.....

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.....[2]